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BUOYANT DEVICE FOR BI-DIRECTIONAL ACOUSTO-OPTIC
SIGNAL TRANSFER ACROSS THE AIR-WATER INTERFACE

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT (1) LYNN T. ANTONELLI and (2) FLETCHER A. BLACKMON, employees of the United States Government, citizens of the United States of America, and residents of (1) Cranston, County of Kent, State of Rhode Island, and (2) Forestdale, County of Barnstable, Commonwealth of Massachusetts, have invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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1 Attorney Docket No. 83723

2
3 BUOYANT DEVICE FOR BI-DIRECTIONAL ACOUSTO-OPTIC
4 SIGNAL TRANSFER ACROSS THE AIR-WATER INTERFACE
5

6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and used
8 by or for the Government of the United States of America for
9 governmental purposes without the payment of any royalties
10 thereon or therefor.
11

12 BACKGROUND OF THE INVENTION

13 (1) Field of the Invention

14 The present invention relates to an improvement for
15 communicating across the air-water interface. More particularly,
16 the invention relates to a cost-effective buoy system responsive
17 to in-air laser beams and underwater acoustic transducers
18 receiving and transmitting acoustic signals for bi-directional
19 transfer of information between in-air and underwater
20 environments.

21 (2) Description of the Prior Art

22 Effective bi-directional transfer of information between in-
23 air and underwater platforms has been long sought since such a
24 capability would increase the autonomy and flexibility of
25 subsurface, surface, and air vehicles engaged in undersea

1 warfare. However, signal transfer by contemporary communications
2 systems has been complicated by the fact that efficient in-air
3 signal propagation is accomplished through radio frequency (RF)
4 transmissions while acoustic pressure waves are the most
5 efficient means underwater. Unfortunately, RF signals do not
6 penetrate or propagate well in water, and underwater generated
7 acoustic signals do not readily penetrate into the air
8 environment. Optical signals, such as laser beams can operate in
9 both air and water environments; however, their depth range in
10 water is limited by water clarity (signal attenuation) to
11 typically within one hundred meters or less.

12 Consequently, the primary method of underwater sonar and
13 communications relies on acoustic signal generation and
14 propagation through the water using submerged acoustic
15 transmission hardware.

16 The generation of underwater sound from an aerial platform
17 therefore poses a challenge. Active surface ship sonar and aerial
18 dipping sonar devices such as disclosed in U.S. Patent No.
19 5,856,954 could be used for this purpose at the risk of the
20 transmitting platform giving away its position.

21 Optical signals from lasers have been found to propagate
22 well in air (depending on environmental conditions such as fog or
23 rain) and are more covert than RF transmissions due to their
24 confined beam width, and an opto-acoustic communication system
25 has been developed that takes advantage of this. The opto-

1 acoustic system (technique) provides a method for transmitting an
2 acoustic waveform from an in- air platform into the water via
3 conversion of optical energy at and/or slightly below the air-
4 water interface. In the linear regime of opto-acoustics, a laser
5 beam incident at the boundary is exponentially attenuated by the
6 medium thus producing local temperature fluctuations that give
7 rise to volume expansion and contraction. The volume fluctuations
8 in turn generate a propagating pressure wave. The effect of the
9 medium's attenuation on the laser light is to produce an array-
10 like structure of thermo-acoustic sources that generate modulated
11 pressure waves at the laser amplitude and modulation frequency of
12 the modulating laser signals. In the non-linear regime of opto-
13 acoustics, the types of physical phenomena that are produced are
14 based on optical energy density and intensity considerations.
15 Broadband acoustic transients with considerable acoustic energy
16 are created in the water. The laser pulse repetition rate can
17 also be used to transmit selected acoustic frequencies for sonar,
18 command and control, and communications purposes. For example,
19 this approach can control steering of unmanned underwater
20 vehicles (UUVs) and torpedoes.

21 A level of covertness and safety can be obtained using an
22 opto-acoustic system that has been devised to remotely generate
23 underwater acoustic signals. Sound Pressure Levels (SPL) of up to
24 200 dB// μ Pa have been achieved by directing a focused, high-
25 powered, infrared, pulsed laser beam onto the water surface. The

1 effect of the high energy/intensity laser incident at the water's
2 surface is to produce a change in the phase of the water medium
3 from water to vapor and/or plasma producing an explosive, thermo-
4 acoustic source that generates modulated pressure waves at the
5 laser amplitude and modulation frequency of the modulating laser
6 signals. The remote nature of the aerial source insures that the
7 source of the underwater acoustic transmission remains unknown to
8 underwater platforms. Likewise, the in-air optical signal used
9 for generating an underwater acoustic signal remains covert to
10 in-air platforms. This method provides a means for remote, aerial
11 generation of underwater sound, breaching the air-water
12 interface.

13 However, the opto-acoustic technique requires high power
14 pulsed lasers and focusing optics for efficient conversion of
15 optical to thermo-acoustic energy. Also, the performance of the
16 opto-acoustic conversion is affected by the oblique laser
17 incidence angle at the air-water boundary, sea state roughness,
18 and by in-water impurities.

19 Due to the large acoustic impedance mismatch between the air
20 and water environments, underwater acoustic signals do not
21 significantly penetrate into the air. Traditionally, underwater
22 acoustic sonar requires in-water hardware for acoustic signal
23 generation and reception. This alone makes it difficult to
24 acoustically communicate across the air-water interface between
25 underwater platforms such as UUVs and submarines and surface

1 platforms from ships, unmanned aerial vehicles (UAVs), aircraft,
2 ground based platforms and satellites. Thus, buoys were designed
3 to receive underwater acoustic signals via underwater propagation
4 or propagation through a direct tethered link and then reradiate
5 the information as Radio Frequency (RF) signals into the air for
6 subsequent detection by land or air-based platforms, see for
7 example U.S. Patents Nos. 6,058,071 and 5,592,156. Typically, RF
8 signals broadcast to a large area for data reception. This is
9 advantageous in that RF signals can be detected at great
10 distances and relayed through satellites. However, the process is
11 less covert and can lead to unwanted signal interception.

12 An alternative, the laser Doppler vibrometer (LDV) detection
13 method had been devised to detect underwater acoustic signals by
14 directly probing the water surface with a laser beam. This method
15 is used for detecting acoustic signals by measuring velocity
16 perturbations (vibrations) derived from the sound pressure at the
17 surface of the water, and this capability may be applied to
18 uplink communications between underwater and in-air platforms as
19 well as aerial detection of any underwater sound for applications
20 including marine mammal detection and tracking, and defense of
21 surface ships from wake homing torpedoes. The LDV provides a
22 means for covert and remote, aerial detection of underwater
23 sound, breaching the air-water interface.

24 However, applying a commercial LDV involves obtaining narrow
25 beam laser returns from the specularly reflecting water surface.

1 Initial tests on hydrodynamic surfaces indicate that signal
2 dropout occurs due to optical reflections arriving outside of the
3 optical detector's sensing area. Signal information is therefore
4 lost intermittently and randomly, which is a detriment especially
5 for communications applications. Irrespective of the performance
6 of the LDV-based sensor improves with higher optical
7 reflectivity, the air-water interface reflects only approximately
8 2% of the incident laser radiation and therefore limits the
9 efficiency of this application of LDV sensors.

10 Thus, in accordance with this inventive concept, a need has
11 been recognized in the state of the art for a buoyant device that
12 enables optically controlled, bi-directional transfer of
13 underwater sound between in-air and underwater environments that
14 assures covert in-air operations using spatially confined, low--
15 powered laser beams for triggering underwater transmission and
16 for optically detecting the underwater sound.

18 SUMMARY OF THE INVENTION

19 The first object of the invention is to provide a buoy
20 device for covertly, optically controlling, bi-directional
21 transfer of underwater sound and optical laser signals between
22 in-air and underwater environments.

23 Another object of the invention is to provide a buoy system
24 for both translating in-air optical signals to underwater
~~25 acoustic signals and translating underwater acoustic signals to~~

1 optical signals transmitted through air for remote, optical
2 reception.

3 Another object is to provide a cost-effective buoy to
4 remotely generate underwater sound of known spectral content,
5 amplitude, and phase and enhance aerial, optical detection of the
6 underwater sound.

7 Another object is to provide a buoy using spatially
8 confined, low-powered laser beams for triggering underwater
9 transmission and optical detection of underwater sound.

10 Another object is to provide a buoy system using in-air
11 laser beams and underwater acoustic transducers for bi-
12 directional transfer of information between in-air and underwater
13 environments.

14 Another object is to provide a buoy system using in-air
15 laser beams and underwater acoustic transducers for bi-
16 directional transfer of information between in-air and underwater
17 environments for uplink and downlink communications and control
18 of vehicles such as UUVs and torpedoes across the air-water
19 interface.

20 Another object is to provide a buoy system using in-air
21 laser beams and underwater acoustic transducers for bi-
22 directional transfer of information between in-air and underwater
23 environments that reduces laser power requirements and the
24 difficulties associated with direct opto-acoustic conversion

1 while maintaining in-air covert operation and remote access to
2 the transmitting buoy.

3 Another object is to provide a buoy system enhancing the
4 optical reflectivity and sensitivity for the acousto-optic (LDV-
5 based) sensing technique while maintaining covert and remote,
6 aerial access of underwater acoustic signal information.

7 Another object is to provide a buoy operating in an active
8 mode by accepting a low-power laser beam delivering a signal
9 through the air from a remote source to activate the buoy's
10 underwater acoustic transmitter.

11 Another object is to provide a buoy operating in the passive
12 mode to detect underwater sound with underwater acoustic
13 transducers and translate the detected sound into amplified
14 vibrations that are probed by laser signals from a remote LDV
15 sensor to allow retrieval of the detected underwater sound.

16 These and other objects of the invention will become more
17 readily apparent from the ensuing specification when taken in
18 conjunction with the appended claims.

19 Accordingly, the present invention is for a buoy system for
20 bi-directional communications in-air and underwater. A hollow
21 shell of a buoy floating on water has an upper portion in air
22 above the surface of water and a lower portion below the surface
23 of the water. An array of acoustic transducers is disposed in the
24 lower portion for receiving acoustic signals and for transmitting
25 acoustic signals through the water. A dome-shaped retro-

1 reflective coating on the upper portion is vibrated in accordance
2 with acoustic or other gathered information bearing data signals
3 for retro-reflecting impinging laser illumination signals through
4 air and conveying the acoustic and other information bearing data
5 signals as retro-reflected data signals in air. The retro-
6 reflective coating is controlled to vibrate in response to
7 impinging laser control signals through air and an array of
8 photo-detectors on the upper portion of the buoy are responsive
9 to the impinging laser control and information signals. A
10 control/memory/GPS module and acoustic processing-electronics
11 section in the shell receives activation signals from the retro-
12 reflective coating and photo-detector array and couples received
13 acoustic signals from the transducer array and from memory as
14 data signals to the retro-reflective coating. An array of
15 electro-mechanical vibration shakers inside of and against the
16 upper portion of the shell is driven by the optic-processing
17 module for vibrating the retro-reflective coating, and an annular
18 array of accelerometers is connected to the optic-processing
19 module to monitor vibratory motion of the retro-reflective
20 coating. Transducer elements are interspersed with the vibration
21 shaker array under the dome-shaped retro-reflective coating. The
22 transducer elements are connected to the optic processing module
23 for generating signals representative of the impinging laser
24 control and information signals. The representative generated
25 signals from the transducer elements are coupled to the

1 control/memory/GPS module to initiate retrieval of the
2 information of received acoustic signals from the transducer
3 array and memory in the control/memory/GPS module. A
4 transmit/receive switch is connected to the control/memory/GPS
5 module, acoustic processing-electronics section, and the
6 transducer array to selectively enable operation of the
7 transducer array in the passive mode and the active mode. A
8 remote platform has at least one laser onboard for transmitting
9 the impinging laser illumination signals and impinging laser
10 control signals through the air. The remote platform also has a
11 laser Doppler vibrometer-based sensor responsive to receive the
12 data signals as the retro-reflected data signals through the air.

13

14

BRIEF DESCRIPTION OF THE DRAWINGS

15 A more complete understanding of the invention and many of
16 the attendant advantages thereto will be readily appreciated as
17 the same becomes better understood by reference to the following
18 detailed description when considered in conjunction with the
19 accompanying drawings wherein like reference numerals refer to
20 like parts and wherein:

21 The figure is a schematic cross-sectional representation of
22 the buoy system of the invention for covertly bi-directionally
23 translating in-air optical signals and underwater acoustic
24 signals.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the figure, buoy system 10 of the invention has a buoy 10A operationally deployed as it floats on water 2. Buoy 10A has a hermetically sealed metal outer shell 12 to assure that an upwardly extending dry-side portion 14 projects upwardly above waterline 3 into surrounding air 5 and a lower wet-side portion 16 extends into water 2. Metal outer shell 12 could be a flexible, inflatable structure that may resist radar reflections for further covertness. Buoy 10A has a centrally located power supply 17 for supplying electrical power to all its components to be described that need electrical power, and suitable ballast chambers 18 are schematically shown for maintaining buoyancy and proper vertical orientation. Power supply 17 is most likely to be batteries, but solar energy receptor/converters might be used as well as a converter of kinetic energy from ocean waves. An anchor line 19 can be connected to lower portion 16 and extend to an anchor (not shown) on the bottom when mooring is desirable.

Lower portion 16 has a nearly hemispherically-disposed array of acoustic transducers 20 inside of shell 12 of lower portion 16. Lower portion 16 also has a protective acoustically transparent cover 21 to allow bi-directional transfer of acoustic energy signals 22, 24 by transducer array 20. That is, transducer array 20 covered by protective, acoustically transparent cover 21 is capable of both detection of impinging acoustic signals 22 and transmission of projected acoustic signals 24. The bi-directional

1 transfer of signals 22, 24 is controlled by transmit/receive
2 switch 26 connected to transducer array 20. Switch 26 can control
3 transducer array 20 to operate in the passive mode and receive
4 impinging acoustic signals 22 from distant signal sources of
5 interest through water medium 2, or operate in the active mode to
6 transmit acoustic signals 24 through water medium 2. Acoustic
7 processing-electronics section 30 and control/memory/GPS module
8 40 in upper portion 14 are connected to operate transmit/receive
9 switch 24 and transducer array 20.

10 Upper portion 14 has an annular array of photo-detectors 50
11 on shell 12 exposed through small transparent sealed windows 12A
12 in shell 12 to receive remote optical signals transmitted through
13 air 5 and connect activation signals to an optic-processing
14 module 60. Optical processing module 60 also is connected to
15 control/memory/GPS module 40 and an array of electro-mechanical
16 vibration shakers 70 that extend around and down the inside of
17 upper portion 14 of shell 12. Electro-mechanical vibration

18 shakers 70 are driven by optic-processing module 60 to
19 responsively vibrate a dome-shaped retro-reflective coating 80 on
20 upper portion 14, and an annular array of accelerometers 90 is
21 connected to optic-processing module 60 to allow monitoring of
22 the vibratory motion of retro-reflective coating 80.

23 Low-power laser beams (shown as arrows 6A) can be
24 transmitted from a remote laser source 6 on a remote platform 8
25 of buoy system 10, such as an aircraft or land-based platform.

1 Laser beams 6A are directed at buoy 10 A where they can be
2 detected by photo-detector array 50 on upper portion 14 of buoy
3 10A. Since photo-detector array 50 annularly extends about shell
4 12, it can receive and capture the control and other information
5 of laser beam 6A from all directions around shell 12 and couple
6 it to optical processing electronics module 60. Optical
7 processing electronics module 60 inside upper portion 14
8 generates signals representative of activation signals from laser
9 signals 6A for operation of buoy system 10. These activation
10 signals can be representative of control commands and/or
11 information of laser signals 6A such as to control transducer
12 array 20 to receive acoustic signals 22 or transmit the
13 information of laser beam 6A as acoustic signals 24 into water 2.
14 Laser beam signals 6A could also be used for other control of
15 components of buoy 10A. Thus, since laser beam 6A is narrow and
16 does not "spill-over" to other areas and be intercepted, laser
17 beam 6A can be used for covert remote control or activation of
18 transducer array 20.

19 When the buoy 10A is deployed on water 2, transducer array
20 20 is submerged and outwardly facing in water 2 for efficient
21 acoustic reception and transmission of the underwater sound
22 signals 22, 24. Transducer array 20 of buoy system 10 can be
23 switched between active (projection) and passive (detection)
24 modes in response to remote control signals of beam 6A via
25 transmit/receive switch 26. The transmit/receive switch 26

1 receives appropriate signals representative of laser signals 6A
2 from interconnected electronics module 60 via control/memory/GPS
3 module 40 and the acoustic processing-electronics section 30.
4 Control/memory/GPS module 40 of buoy 10A has an internal memory
5 storage such that acoustic signals can be collected, stored, and
6 then delivered into the water 2 at a precise time (or delay) as
7 designated by remotely originating optical command signals 6A.
8 Memory of module 40 can also store the information of laser beam
9 signals 6A for later acoustic transmission by transducer array 20
10 after a predetermined delay or when a subsequent laser signal 6A
11 controls such transmission. In addition, control/memory/GPS
12 module 40 has Global Positioning System (GPS) for covert
13 identification of buoy position by host platform (remote platform
14 8). GPS is located in Control/memory/GPS module 40 and is
15 appropriately connected to an antenna 41 on shell 12 to receive
16 GPS coordinates and, optionally, to relay the position of buoy
17 10A to remote platform 8. A capability for electromagnetically
18 transmitting the location of buoy system 10 to host platform 8
19 via antenna 41 may also be included; however, such transmissions
20 may be more susceptible to unwanted interception. This relay of
21 information might also be done by appropriate coded vibrations of
22 retro-reflective coating 70 after an interrogation command for
23 the buoy's location has been received at buoy 10A via laser
24 signal 6A or by laser signal 7A.

1 The acoustic processing-electronics section 30 of buoy 10A
2 is internally connected to receive acoustic signals from acoustic
3 transducers 20 and photo-detector array 50 via optic processing-
4 electronics module 60 and control/memory/GPS receiver module 40.
5 This information is to be used for deciphering remote control
6 signals optically detected by photo-detector array 50, and for
7 processing passive acousto-optic signals and active opto-acoustic
8 signal information for responsive operation of buoy 10A.

9 Buoy 10A also can be remotely controlled to detect impinging
10 acoustic signals 22 through water 2 in a passive mode by
11 underwater acoustic transducers 20. Signals representative of
12 monitored acoustic signals 22 can be stored into system memory in
13 control/memory/GPS module 40 or can be transferred immediately
14 for responsive operation of other components of buoy system 10 as
15 dictated by remote control commands in laser beam 6A. Immediate
16 transfer of data is accomplished by translating the
17 representative signals of the detected acoustic signals 22 into
18 representative amplified vibrations of dome-shaped retro-
19 reflective coating 80. The vibrations of retro-reflective coating
20 80 are excited by electro-mechanical vibration shaker array 70
21 that has its aggregate vibrating surface coupled to the inner
22 side of upper portion 14 of metal shell 12.

23 An external, low-power laser Doppler vibrometer-based
24 sensor 9 on remote platform 8 would then probe retro-reflective
25 coating 80 on upper portion 14 of shell 12. This is done by

1 transmitting a low-power illuminating beam 7A from laser 7 on
2 platform 8 to impinge upon the now vibrating retro-reflective
3 coating 80 on shell 12, and then sensing a retro-reflected laser
4 beam portion 7B of illuminating laser beam 7A in system 9 on
5 platform 8. That is, reflected portion 7B would be retro-
6 reflected from retro-reflective coating 80 to laser Doppler
7 vibrometer-based sensor 9, and the information content of the
8 vibrations of retro-reflective coating 80 would be in reflected
9 portions 7B to remotely retrieve the detected underwater sound of
10 signals 22 at platform 8. Vibrometer-based sensor 9 could be a
11 Model OFV-353 Doppler vibrometer developed and marketed by
12 Polytec PI of 23 Midstate Drive, Auburn, MA 01501, Polytec PI,
13 for example.

14 The term illuminating as used herein is not intended to mean
15 that laser beam 7A or reflected portion 7B is necessarily visible
16 to the eye, but it can be in a variety of different wavelengths
17 emitted by lasers to achieve the desired vibrations of retro-
18 reflective coating 80 and retro-reflections as discussed herein.

19 In addition the mere receipt of illuminating laser beam 7A at
20 photo-detector array 50 may be used to control or trigger the
21 activation of vibration shaker array 70 to vibrate retro-
22 reflective coating 80 and create retro-reflected signals 7B.

23 The information content of the reflected signals 7B sensed
24 by sensor 9 is enhanced by buoy 10A of the invention in
25 comparison to the quality of the sensed signals of the acousto-

1 optic sensing technique using high-power laser energy as
2 discussed in the prior art technique in the Background supra.
3 Retro-reflective coating 80 on shell 12 of buoy 10A provides an
4 enhanced in-air optical reflection for subsequent signal
5 acquisition by the external, remote, laser vibrometer sensor 9 on
6 remote platform 8. Buoy 10A of the invention enhances the in-air
7 detection performance of external sensor 9 with respect to
8 increasing sensitivity of acoustic detection and maintains a high
9 probability of reflection for reduced signal dropout. This
10 enhanced capability is achieved with relatively low power
11 illuminating laser signals 7A in buoy system 10 as compared to
12 the technique of the prior art.

13 Buoy 10A can operate in an active mode when low-power laser
14 beam 6A is transmitted through air 5 from laser 6 on remote
15 platform 8 to buoy 10A for controlling or activating transducer
16 array 20 to transmit acoustic signals 24 and receive reflected
17 acoustic signals 22. Photo-detector array 50 is open through

18 transparent windows 12A to air environment 5 to receive laser
19 beam signals 6A and generate activation signals for optic
20 processing-electronics module 60 that processes the optical
21 signal and responsively activates transducer array 20 via
22 control/memory/GPS receiver module 40. In response to remote
23 command signals 6A, buoy system 10 provides opto-acoustic
24 transduction remotely and covertly at low cost for easier and
25 more effective implementation of a laser-based aerial

1 transmission of what will be underwater sound. The information of
2 laser beam signal 6A is transmitted at sufficient low-power from
3 platform 8 to get to and control operations of buoy system 10.
4 This feature eliminates any need for airborne high-power lasers
5 for thermo-acoustic interaction at the water's surface.

6 Since the upper portion 14 of shell 12 has dome-shaped
7 retro-reflective coating 80 exposed to and positioned in air
8 environment 5, buoy 10A also may be optically probed by
9 illuminating laser beam 7A from a laser 7 on platform 8 to
10 acquire underwater acoustic information 22 that is being and has
11 been acquired by transducer array 20 and stored in
12 control/memory/GPS module 40. The optical energy of narrow low-
13 power illuminating laser beam 7A can cause vibrations of retro-
14 reflective coating 80 that are transmitted through metal shell 12
15 and to transducer elements 75 that are interspersed with
16 individual shakers of vibration shaker array 70 under dome-shaped
17 retro-reflective coating 80. Transducer elements 75 could be

18 piezoelectric chips connected to optical processing module 60
19 that generate activation signals representative of the
20 information (that could be control signals) of impinging laser
21 beams 7A. The representative activation signals are coupled to
22 control/memory/GPS module 40 and may initiate the retrieval of
23 the information of received acoustic signals 22 that has been
24 stored in module 40 or being currently received by transducer

1 array 20. This control by beam 7A can be in place of control by
2 laser beam 6A if desired.

3 The information of received acoustic signals 22 will be
4 retrieved by optical processing-electronics module 60 from
5 control/memory/GPS module 40 and coupled to vibration shaker
6 array 90. Vibration shaker array 70 generates vibrations of upper
7 portion 14 of shell 12 and retro-reflective coating 80 that are
8 representative of the received acoustic signals 22.

9 Since retro-reflective coating 80 is matched to wavelengths
10 of emissions from remote platform 8, it can retro-reflect laser
11 beam portions 7B of illuminating laser beam 7A that impinge on
12 it. Consequently, the representative vibrations of retro-
13 reflective coating 80 responsively modulate reflected portions 7B
14 which are received by vibrometer-based sensor 9 which can
15 determine the information content of portions 7B. The retro-
16 reflected portions 7B thusly can carry the information of
17 presently acquired acoustic signals 22, or any other stored

18 information in control/memory/GPS module 40.

19 Thus, retro-reflective coating 80 provides a mechanical
20 means of maintaining the optical reflectivity and enhancing
21 acousto-optic sensitivity for the remote LDV sensing technique.
22 These capabilities improve sensor performance while maintaining
23 covert and remote information access. The buoy's high
24 reflectivity enhances the LDV sensor's optical data reception for
25 continuous data acquisition to reduce the signal dropout which

1 otherwise occurs with surface wave interaction with the high-
2 power interrogating laser beam of the prior art.

3 Optical processing of data in buoy system 10 can be done by
4 electronic components of buoy system 10 for operation in the
5 passive mode. Buoy system 10 can process detected acoustic
6 signals 22 and convert them to responsive amplified vibrations of
7 the upper portion 14 of buoy shell 12 and retro-reflective
8 coating 80. Optic processing-electronics module 60 has a means
9 for acquisition and amplification of acoustic signals 22 from
10 transducer array 20 via control/memory/GPS receiver module 40.
11 Control module 40 will interpret optically received control
12 signals 6A from photo-detector array 40, control the activation
13 of optic processing module 60 and acoustic processing electronics
14 section 30, provide memory storage capability within it, contain
15 a GPS receiver capability within it, control the activation of
16 transmit/receive switch 26 and operational mode of transducer
17 array 20. Detected signals 22 can be amplified by acoustic

18 processing-electronics section 30 and sent to optical processing
19 module 60 and coupled to vibration shaker array 70 for generating
20 vibrations of upper portion 14 and retro-reflective coating 80 on
21 shell that are representative of detected underwater acoustic
22 signals 22 that can be retrieved by remote platform 8 when a
23 narrow-beam interrogation signal 7A impinges on retro-reflective
24 coating 80. Whenever retro-reflective coating 80 is activated to
25 transmit information, annular accelerometer array 90 on buoy

1 shell 12 can monitor vibrations imparted by vibration shaker
2 array 70 to assure the accuracy and validity of information of
3 optically transmitted (retro-reflected) beam 7B when a comparison
4 is made in optic processing module 60 to the intended vibrations
5 of retro-reflective coating 80.

6 Optical processing of data in buoy system 10 can be done by
7 buoy system 10 for operation in the active mode. Buoy system 10
8 can process detected optical signals 6A and convert them to an
9 amplified underwater acoustic transmission signal 24. Optical
10 processing-electronics module 60 is coupled to photo-detector
11 array 50 to acquire signal 6A. Detected signal 6A is passed to
12 control/memory/GPS module 40 and fed to acoustic processing
13 electronics section 30 to create an amplified signal to initiate
14 transmission of acoustic signal 24 by array 50 into water 2.

15 The uncomplicated design of buoy 10A is the first of its
16 kind for translating in-air optical signals of a laser beam to
17 underwater acoustic signals as well as for translating underwater

18 acoustic signals for remote, optical reception of retro-reflected
19 laser signals. The standoff, bi-static sonar technique allows a
20 remote platform 8 of buoy system 10, be it a surface ship or in-
21 air platform or land-based sonar station, to generate acoustic
22 sonar signals at a distance from their controlling (transmitting)
23 platform. The acoustic illumination of the underwater objects can
24 then be detected and analyzed at host platform 8 and used to
25 localize the position of submerged or buried platforms and

1 objects. The active transmissions may also be used to deliver in-
2 air optical signals to underwater sonar communication signals.

3 In the active mode, buoy system 10 allows the use of low
4 power, information carrying lasers on platforms 8 instead of high
5 powered lasers, for opto-acoustic transmission. Since lower
6 powered lasers can be used to trigger buoy 10A to generate
7 underwater acoustic signals 24, the need for high energy lasers
8 is eliminated which is an order of magnitude improvement over
9 thermo-acoustic physic systems of the prior art for generation of
10 underwater sound. Another advantage over thermo-acoustic systems
11 is that buoy system 10 of the invention avoids stringent optical
12 focusing restrictions for gathering data and the limitations
13 associated with changing sea surface conditions. Consequently, a
14 larger selection of many different lasers can be made in platform
15 8 of buoy system 10 including lower power levels and different
16 wavelengths of operation that can be used which are safer for the
17 eyes (pilot's concern) and that can reduce the size and weight of

18 the laser systems on distant platforms 8. In addition buoy system
19 10 can allow use of laser pulse modulation to eliminate the need
20 for high pulse rate, high-power lasers in the infrared wavelength
21 region. Remote transmission of underwater acoustic signals
22 including communication signals and control signals are enabled
23 to allow communications and remote control of UUVs, UAVs, and
24 munitions. Buoy system 10 provides a covert countermeasure
25 capability that also allows in-air covert operation (rather than

1 overt RF signal transmission broadcasts) to control of underwater
2 acoustic transmission. Buoy 10A of buoy system 10 additionally
3 gives an alternative means of generating a sonar signal for
4 underwater object illumination or for downlink underwater
5 communications to a submerged platform. Buoy 10A of buoy system
6 10 can deliver broadband acoustic signals of desired spectral
7 contents, amplitudes, and phases and is a more controllable
8 underwater sound source than 'Distant Thunder' explosions. Buoy
9 system 10 allows a remote host platform 8, (fitted with the low-
10 power lasers), such as a tower, surface ship or in-air platform
11 to generate acoustic sonar signals from a standoff position that
12 can be used to detect and localize the position of
13 submerged/buried platforms and objects either with their own
14 ship's sonar with an external LDV sensor. Buoy 10A of buoy system
15 10 can provide an explosive/chemical payload delivery system for
16 smart mine and counter mine applications, can have a propulsive
17 system to move it and possibly avoid boat traffic or detection,

18 can have adaptive buoyancy in order to raise and lower it, and
19 could have scuttling charges that can be detonated after its
20 usefulness is over. In addition buoy 10A could contain a main
21 charge having sufficient explosive power to inflict damage on an
22 adversary. The buoy system 10 could employ chemical and electro-
23 magnetic sensing devices as well as fuel cells to augment its
24 capabilities. Additional small explosive shaped charges could be
25 contained within the buoy.

1 Buoy system 10 can provide a continuous reflective surface
2 for laser interrogation to detect underwater sound, even when it
3 is subjected to wave motion. Buoy system 10 also provides a
4 standoff, covert method to obtain underwater acoustic sonar
5 information, and a new level of efficient battle-space detection
6 and monitoring can be attained using the combination of several
7 buoys 10A and several remote platforms 8 in buoy system 10 having
8 laser-based sensing (LVD) techniques that can include satellites,
9 lighter-than-air craft, fixed/movable wing, manned/unmanned
10 aircraft, etc. Buoy system 10 enhances the signal to noise ratio
11 of aerial optical detection, and improves LDV sensor detection
12 sensitivity. Besides detecting ambient ocean noises, and marine
13 mammal sounds and shipping noise, buoy 10A may also be used for
14 detecting underwater vessels such as submarines or communications
15 signals from submarines or UUVs. The detected acoustic signals
16 will then be transferred to the upper, air-side portion of buoy
17 system 10 for subsequent aerial detection by remote platform 8.

18 It is understood that other sizes and configurations of buoy
19 10A could be made in accordance with this invention to allow
20 successful operation in different operational scenarios.
21 Irrespective of the exact shape of buoy 10A (including an
22 inflatable design), it must provide an underwater section for
23 acoustic reception and transmission, an optically responsive
24 section for translating detected optical signals into appropriate
25 buoy control commands or for activation of the acoustic

1 transmission signal, and an electronics section coupled to each
2 other sections for bi-directionally translating between the
3 acoustic and optical signals. Furthermore, optically retro-
4 reflective coating 80 on shell 12 that is in contact with air 5
5 can be interlaced with photo-detectors of array 50 in different
6 orientations instead of the annular disposition as discussed
7 above to assure acceptable optical signal reception of laser
8 signals 6A and 7A. Retro-reflective coating 80 and the photo-
9 detector array 50 on upper portion 14 of buoy system 10 should be
10 made to be responsive to the wavelengths of laser radiation 6A
11 and 7A and can be tailored or modified to include many other
12 wavelengths of laser radiation so long as retro-reflective
13 coating 80 is capable of reflecting portions 7B of the other
14 wavelengths of laser radiation. In this regard, optical laser
15 signals 6A, 7A sent to buoy system 10 may contain either the
16 exact waveform to be converted to a transmitted acoustic signal
17 24 or optical signals 6A, 7A may transfer coded signals to be

18 interpreted by optic-processing module 60 and control/memory/GPS
19 module 40 in buoy system 10 for designation of the signal
20 waveform and/or remote control of operation of buoy system 10.

21 Transducer array 20 can be different than shown and
22 described and can be controlled to allow broadband acoustic
23 coverage, create beam patterns, and transmit acoustic energy at
24 different power levels. Ballast chambers 18 may be selectively
25 flooded or purged to allow buoy system 10 to sink or rise to a

1 desired depth and transmit different levels of acoustic energy
2 into the water with a reduced, probability of cavitation to
3 remain covert.

4 Optionally, or in addition to the components described
5 above, buoy 10A also can have an onboard laser 95 with an optical
6 system 97 connected to optic processing module 60. Optical system
7 97 suitably aims and aligns onboard laser 95 to emit an emitted
8 laser beam 96 to platform 8 to transmit data and/or other
9 information and control signals from buoy 10A to platform 8. For
10 example, optical system 97 for onboard laser 95 could have an
11 appropriately interconnected photo-cell arrangement that senses
12 the direction where an interrogating beam from platform 8 is
13 coming from to point onboard laser 95 in this direction during
14 emission of beam 96. This capability provided by onboard laser 95
15 can be used as a primary up-link to platform 8 or other
16 designated receiving station or could be used as a back-up for
17 the other aforescribed components.

18 One skilled in the art to which this invention applies could
19 make such changes without departing from the scope of this
20 invention herein described. Having this disclosure in mind,
21 modifications calling for selection of suitable components from
22 among many proven contemporary designs and compactly interfacing
23 them in buoy system 10 can be readily done without requiring
24 anything beyond ordinary skill.

1 The disclosed components and their arrangements as disclosed
2 herein all contribute to the novel features of this invention.
3 Buoy system 10 as described herein provides a cost-effective
4 means of bidirectionally transferring information across the air-
5 water interface for long term reliable operation in harsh marine
6 environments. Therefore, buoy system 10 as disclosed herein is
7 not to be construed as limiting, but rather, is intended to be
8 demonstrative of this inventive concept.

9 It will be understood that many additional changes in the
10 details, materials, steps and arrangement of parts, which have
11 been herein described and illustrated in order to explain the
12 nature of the invention, may be made by those skilled in the art
13 within the principle and scope of the invention as expressed in
14 the appended claims.

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2
3 BUOYANT DEVICE FOR BI-DIRECTIONAL ACOUSTO-OPTIC
4 SIGNAL TRANSFER ACROSS THE AIR-WATER INTERFACE
5

6 ABSTRACT OF THE DISCLOSURE

7 A buoy system bi-directionally communicates in-air and
8 underwater. A buoy having a shell to float on water has an upper
9 portion in air and a lower portion in water. An array of acoustic
10 transducers which is disposed in the lower portion receives
11 acoustic signals and transmits acoustic signals. A dome-shaped
12 retro-reflective coating on the upper portion is vibrated for
13 retro-reflecting impinging laser illumination as data signals in
14 air. An array of photo-detectors on the upper portion are
15 responsive to impinging laser control signals and/or signals
16 which may be transmitted as acoustic signals in water.

FIG. 1

